NOTES AND CORRESPONDENCE

A Simple Seasonal Forecast Update of Tropical Cyclone Activity

JOHNNY C. L. CHAN

Laboratory for Atmospheric Research, Department of Physics and Materials Science, City University of Hong Kong, Hong Kong, China

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ABSTRACT

A simple method based on the cumulative number of tropical cyclones (TCs) up to a given month in the early season is proposed to update the seasonal prediction of the annual number of TCs in a given ocean basin. For the western North Pacific, if this number is below normal by July or August, it is very likely that the annual activity will also be below normal. The reverse (for relating above-normal number with above-normal annual activity) is also true although the probability is smaller than for the below-normal category. Similar results are found for TCs in the eastern North Pacific and the North Atlantic, with the latter having the smallest likelihood. These results change only slightly when the samples are separated into dependent and independent subsets.

1. Introduction

Seasonal forecasting of tropical cyclone (TC) activity based on statistical methods has been made in various ocean basins for the past 1 or 2 decades (Camargo et al. 2007). Verifications of the forecasts show that they have some skill (Klotzbach 2007). Most of these forecasts are made before or at the beginning of the TC season, and updates are also sometimes made at the early part of the season (e.g., Chan et al. 2001; Gray et al. 1993). Both the initial forecasts and the subsequent updates are derived from atmospheric and/or oceanographic conditions in prior months or from future conditions predicted from global climate models (Saunders and Lea 2005).

In this note, a simple method to predict the probability of a season being above or below normal based on what has happened in the early season is presented. The data used are first described in section 2. The basic concept behind the prediction model is then discussed in section 3. The methodology used is illustrated in section 4 using the TC activity for the western North Pacific (WNP), together with a presentation of the results. The same methodology is then applied to the Atlantic and the eastern North Pacific in section 5. A summary and a discussion on the possible limitations of this method are given in section 6.

2. Data

The method has been tested for three major ocean basins in the Northern Hemisphere: western North Pacific (WPAC), eastern North Pacific (EPAC), and North Atlantic (ATL). For WPAC TCs, data from the Joint Typhoon Warning Center are extracted (see http://metocph.nmci.navy.mil/jtwc/best_tracks/wpindex.html). For EPAC and ATL TCs, the data are from the National Hurricane Center Web site (http://www.nhc.noaa.gov/tracks1851to2007_atl_reanal.txt for ATL and http://www.nhc.noaa.gov/tracks1949to2007_epa.txt for EPAC). For all three ocean basins, the data are for the years 1960–2005. Only those TCs that reached at least tropical storm intensity (i.e., ≥ 17 m s^{-1}) are included in this study.

3. Basic concept

The basic concept behind the method is that the formation of TCs requires sufficient energy from the at-

Corresponding author address: Johnny Chan, Dept. of Physics and Materials Science, City University of Hong Kong, Tat Chee Ave., Kowloon, Hong Kong, China.
E-mail: johnny.chan@cityu.edu.hk

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TABLE 1. Probability (%) based on categorization I that for a particular ocean basin (WPAC, ATL, and EPAC), if a year has below- or above-normal cumulative TC activity by the end of various months (May, June, July, and August for WPAC, and July and August for ATL and EPAC), then the same year will have below- or above-normal TC activity, respectively, by the end of the year in that ocean basin. The cumulative number thresholds used are listed below each probability for reference.

	WPAC				ATL		EPAC	
	May	Jun	Jul	Aug	Jul	Aug	Jul	Aug
Below normal	64%	71%	87%	96%	46%	62%	95%	96%
	≤3	≤4	≤8	≤14	≤1	≤4	≤5	≤9
Above normal	61%	60%	78%	83%	50%	70%	79%	83%
	≥4	≥5	≥9	≥15	≥2	≥5	≥6	≥10

mosphere and the ocean, and that even when this amount of energy is available, the atmospheric and oceanic conditions must be conducive for such formation (Gray 1968). Further, in a given month, the amount of such energy available is likely to have a climatological limit, such as the thermal energy from the ocean and the kinetic energy associated with the atmospheric flow. Therefore, if the atmospheric and oceanic conditions in the early part of the TC season are not favorable for TC formation, the total number of TCs for the rest of the season is less likely to be above normal because many of these conditions especially in the tropical regions tend to persist for a relatively long period of time. Even if these conditions become more favorable later in the season, because of the climatological limit on the amount of energy available, it would be difficult for the number of TCs in the remaining months of the year to "catch up" to the mean annual number of TCs. If this assumption is correct, the cumulative number of TCs in the early part of the TC season then provides a strong indicator for the annual number of TCs. This hypothesis is tested first for the WNP and by categorizing the frequency of occurrence in two ways. The details of each categorization are described in the next section using the TC activity in the WNP as an illustration.

4. Methodology and results for the western North Pacific

In each of the two categorizations used, the cumulative number of TCs from January to the ith month in each year j is first calculated. The difference in the two categorizations lies in the way the sample is divided. The data from WPAC are used to illustrate how the two categorizations are applied. The results from the other two basins are then presented in section 5.

a. Categorization I

The sample is divided into two groups. For each year j, the cumulative number in the ith month, N_{ij}, is compared to the mean cumulative number in the ith month for the entire sample, M_i. The year j is then classified as below or above normal up to the ith month according to the following criterion:

- below normal if $N_{ij} < M_i$
- above normal if $N_{ij} \geq M_i$.

As an example, the mean for the cumulative WPAC TC number at the end of July (i.e., M_7) is 8.96. Then, a year with $N_{ij} \leq 8$ will be considered below normal and a year with $N_{ij} \geq 9$ above normal. The annual number of WPAC TCs for each year is also classified in the same way. For WPC, a below-normal year will have 27 or less TCs and an above-normal year 28 or more TCs.

With this classification, the label of a particular year (below or above normal) is compared with the label of the same year for a particular month. Then, the probability that if a year has below-normal cumulative TC activity by the ith month then that year will have below-normal TC activity by the end of the year can be computed (Table 1).

The results in Table 1 are interpreted as follows: take July as an example. If the cumulative TC number at the end of July is below normal (≤8), then the chance for the annual TC number to be below normal (≤27) is 87%. Similarly, if the cumulative TC number at the end of July is above normal (≥9), then the chance for the annual TC number to be above normal (≥28) is 78%. Obviously, as the season marches on, the probability for both categories increases.

Two important conclusions can be drawn. The assumption made in section 3 is to a large extent valid. That is, by the end of July, if the TC number is still below normal, it is very likely that TC activity for the entire season will be below normal. If the situation persists by the end of August, this conclusion reaches almost total certainty. The second important finding is that the probability for the above-normal category is less. This means that even if the atmospheric and oceanic conditions in the early part of the season allow the formation of more than the normal number of TCs, the

TABLE 2. Probability (%) based on categorization II that for a particular ocean basin, if a year has below- or above-normal cumulative TC activity by the end of various months (May–August for WPAC, August for ATL, and July and August for EPAC), then the same year will have below- or above-normal TC activity, respectively, by the end of the year in that ocean basin. The cumulative number thresholds used are listed below each probability for reference.

	WPAC				ATL	EPAC	
	May	Jun	Jul	Aug	Aug	Jul	Aug
Below normal	70%	79%	100%	100%	75%	100%	100%
	≤2	≤3	≤7	≤12	≤3	≤4	≤7
Above normal	61%	56%	84%	88%	85%	87%	89%
	≥4	≥6	≥11	≥17	≥6	≥7	≥11

entire TC season may not necessarily have above-normal activity. Presumably, whether this latter situation occurs depends on whether such conditions continue to persist throughout the season.

b. Categorization II

The sample is divided into three groups. The year j is classified as below normal, normal, or above normal up to the ith month according to the following criterion:

- below normal if $N_{ij} < (M_i - 0.5\sigma_i)$
- normal if $(M_i - 0.5\sigma_i) \leq N_{ij} \leq (M_i + 0.5\sigma_i)$
- above normal if $N_{ij} > (M_i + 0.5\sigma_i)$

where σ_i is the standard deviation of the cumulative number of TCs up to the ith month. As an example, the mean and standard deviation for the cumulative WPAC TC number at the end of July (i.e., M_7 and σ_7, respectively) are 9.0 and 3.4, respectively. Then, a year with $N_{ij} \leq 7$ will be considered below normal and a year with $N_{ij} \geq 11$ above normal, with the rest being normal years. However, the annual number of TCs for each year is classified in the same way as in categorization I (i.e., only above or below normal).

The results using this categorization (Table 2) give even better results. Again, taking July as an example, if the cumulative TC number at the end of July is below normal (≤7), then it is certain (based on the data in this study) for the annual TC number to be below normal (≤27). Similarly, if the cumulative TC number at the end of July is above normal (≥11), then the chance for the annual TC number to be above normal (≥28) is 84%. Consistent with categorization I, as the season marches on, the probability for both categories increases.

c. Dependent versus independent samples

The results from the last two subsections are derived based on the entire data sample of 46 yr. A natural question to ask is how the probabilities might change if an independent dataset is used.

To address this question, the following procedure is employed. Consider first categorization I. Among the 46 yr, 23 are selected randomly. Based on these 23 yr, the mean annual number of TCs, A, is computed. The mean cumulative number in the ith month, M_i, is also calculated in the same way. For each year j of the remaining 23 yr, the cumulative number in the ith month, N_{ij}, is compared to M_i and is then classified as below or above normal up to the ith month according to the same criterion [Eq. (1)]. The annual number of this year is also compared with the value of A to classify it as below or above normal. Then, the probability that if a year has below-normal cumulative TC activity by the ith month then that year will have below-normal TC activity by the end of the year can be computed using the 23 yr of independent data.

The same procedure is then repeated 10 000 times. The mean probability is then obtained by averaging the probability for each time. Because of the random nature of the sampling, in some cases only the below-normal or the above-normal years are sampled. In this case, the probability of the independent dataset will be strongly biased one way or the other. Therefore, a restriction has to be set that of the independent 23 yr, at least 3 must have below-normal and at least three above-normal cumulative numbers in the ith month before the probability of the independent sample can be included in the averaging.

As might be expected, the probabilities from this independent sample are lower than those from the entire sample (Table 3). The decrease is slightly more for the below-normal category with the probability in July and August dropping by 7%–8%, while those for the above-normal category remain almost the same. Note that the average values of M_i (i.e., the threshold values) are the same as those for the entire sample.

A similar procedure is also employed for categorization II. The results for the WPAC (Table 4) show a slight decrease in the probability for July and August but an increase for the months of May and June in the above-normal category. Although the probabilities for

TABLE 3. As in Table 1 but for the average probability from 10 000 independent samples. The cumulative number thresholds are the averages from the 10 000 samples.

	WPAC				ATL		EPAC	
	May	Jun	Jul	Aug	Jul	Aug	Jul	Aug
Below normal	65% ≤3	65% ≤4	79% ≤8	89% ≤14	50% ≤1	66% ≤4	81% ≤5	89% ≤9
Above normal	61% ≥4	59% ≥5	77% ≥9	80% ≥15	46% ≥2	65% ≥5	84% ≥6	89% ≥10

July and August in the below-normal category cannot give total certainty as in the dependent sample, they are only a few percent lower.

Thus, the conclusion made in the last two subsections remains valid. That is, for the WPAC, it is possible to predict the activity for the remainder of the season given the known activity during the early or midseason.

5. Results for the Atlantic and eastern North Pacific

a. Atlantic

The same two categorizations are applied to ATL TCs. Because very few TCs form before July, only the cumulative numbers for the months of July and August are examined.

The mean cumulative number of TCs by the end of July and August is, respectively, 1.7 and 4.5. The results obtained using categorization I (Table 1) suggest that if the cumulative number of TCs by August is below normal (1–4), then only 62% of the time will the year have below-normal TCs (i.e., ≤10). If this number is above normal (≥5), the chance of having a year with above-normal TCs (i.e., ≥11) is 70%. These percentages as well as those for the month of July are much smaller than the corresponding ones in the WNP.

The results from the independent sample (Table 3) do not change much from those of the entire sample. In fact, the probabilities for the below-normal category for both July and August actually increase slightly. The conclusions are thus quite robust.

A similar result is obtained using categorization II. The standard deviation of the cumulative number by August is 2.4, so that a year with below-normal cumulative number is one with 1–3 TCs and if the number is ≥6, the year is considered to be above normal. Applying this criterion for August (the number is too small for July), if the cumulative number is between 1 and 3 (≥6), the chance of that year having below-normal (above normal) TCs is 75% (85%), again much smaller than its counterparts in the WNP (Table 2). The corresponding average percentages from the independent samples are 78% and 81%, respectively (Table 4), which again shows the robustness of the predictions.

Why are the ATL results not as useful as those for WPAC? It is likely due to the small number of TCs even up to the month of July and the fact that most TCs in the Atlantic form in August and September. Further, some early- and late-season ATL TCs form from subtropical systems or baroclinic disturbances, the development of which is not likely controlled by tropical conditions associated with the formation of most TCs. In addition, ATL TC activity is quite sensitive to the occurrence of El Niño (e.g., Gray 1984), which may not have an effect on TC activity until later in the season. Nevertheless, the results in this section may still provide some indication of the overall TC activity for the entire season.

b. Eastern North Pacific

Again, because the cumulative number before July is small, only those numbers for the months of July and August are considered. The mean cumulative number

TABLE 4. As in Table 2 but for the average probability from 10 000 independent samples. The cumulative number thresholds are the averages from the 10 000 samples.

	WPAC				ATL	EPAC	
	May	Jun	Jul	Aug	Aug	Jul	Aug
Below normal	73% ≤2	75% ≤3	95% ≤7	99% ≤12	78% ≤3	99% ≤4	96% ≤7
Above normal	64% ≥4	72% ≥6	81% ≥11	87% ≥17	81% ≥6	94% ≥7	96% ≥11

of TCs by the end of July and August is 5.7 and 9.4, respectively.

For categorization I, the percentage for below-normal TCs in July is even higher than that in WPAC (Table 1). If the cumulative number of EPAC TCs by July is ≤5, 95% of the years in the data sample had a below-normal annual number of TCs. This percentage rose slightly to 96% by August, which is the same as that in WPAC. In the above-normal category, the percentages are comparable to those in WPAC.

Interestingly, the probabilities from the independent sample are higher in the above-normal category and lower in the below-normal category (Table 3). However, the changes are not large and thus the conclusion remains valid.

The standard deviations of the cumulative number of EPAC TCs by July and August are 2.3 and 3.4, respectively. Thus, for categorization II, if the cumulative number of EPAC TCs by July is ≤4, it is certain (again based on the data in this study) that the year will have below-normal TCs (≤15; Table 2). The same result is obtained for August. In other words, the results for July and August are the same as those for WPAC. This total certainty is slightly reduced to 99% and 96%, respectively, for July and August if the independent sample is used (Table 4).

The percentages for the above-normal category in the total sample are slightly lower than those in the below-normal category (Table 3). If the cumulative number is ≥7 (11) by the end of July (August), the chance of that year having above-normal TCs is 87% (89%), again similar to the WPAC results. These percentages are actually higher for the independent sample (Table 4).

6. Summary and discussion

a. Summary

A simple method based on the cumulative number of tropical cyclones (TCs) up to a month in the early season has been proposed to update the seasonal prediction of the annual number of TCs in a given ocean basin. The assumption that if the atmospheric and oceanic conditions in the early season are not favorable for TC formation, then it is not likely that the annual TC activity will be above normal is largely valid for two reasons: (i) such conditions tend to persist for a relatively long time especially in the tropics, and (ii) it would be difficult for the atmosphere and/or ocean to support a large number of genesis events during the rest of the season. Therefore, if this number is below normal, it is very likely that the annual activity will also be below normal. The reverse (for relating above-normal number with above-normal annual activity) should also be true.

TABLE 5. Probability (%) based on categorization II that if a year has below- or above-normal cumulative TC activity in the WNP by May, June, July, and August, then the activity for the remaining months will also be below or above normal relative to the mean activity for the remaining months. The bold numbers are from the entire sample of 46 yr and the italicized numbers are averages from the independent samples.

	May	Jun	Jul	Aug
Below normal	**50%**	**50%**	**39%**	**43%**
	54%	*53%*	*38%*	*44%*
Above normal	**50%**	**38%**	**43%**	**63%**
	48%	*42%*	*43%*	*52%*

The results for TCs in the western North Pacific appear to validate this hypothesis so that the cumulative number by the end of, say, July, can serve as a simple way to update the seasonal prediction of TC activity. Similar results are obtained for the eastern North Pacific. Although the results for TCs in the North Atlantic are not as good, the cumulative number by the end of August can still provide a very good indication of what is likely to happen for the rest of the season.

b. Discussion

Two other issues need to be addressed here. First, although the method proposed here is useful as an update in most cases, it is not of much use if the season up to a given month is already above or below the annual mean. The question in such cases is whether for the rest of the year, the number of TCs will continue to be above or below the mean of the remaining months. A more general question then is the following: given the status of TC activity by the end of a given month (i.e., above or below normal), is it possible to predict what will happen for the remainder of the season?

To address this question, the WNP data are examined in the following way: in the below-normal category, the total number of TCs in a particular year j occurring during the remainder of the year following a given month i (i.e., $\Sigma_{k=i+1}^{12} N_{kj}$) is compared with the mean number for the same months from $i + 1$ to December, $M_{i+1,12}$. If $\Sigma_{k=i+1}^{12} N_{kj}$ is $< M_{i+1,12}$, that year is considered below normal for the remainder of the year. The above-normal category is calculated in a similar way. The results show that if a year has below-normal cumulative TC activity by May and June, the probability for TC activity during the remainder of the year to continue to be below the normal mean *of the remaining months* is only 50% (Table 5). This percentage drops to around 40% by July and August. For the above-normal category, the results are similar. Note also that the results from either the entire sample or the average of the independent samples are about the same.

These relatively low percentages may be explained as follows: the original concept is that if a year has below-normal cumulative TC activity by a given month, it is difficult for the atmosphere to generate enough TCs during the remainder of the year to reach the *annual mean*. However, it is possible for the atmospheric and/or oceanographic conditions in these remaining months to be more conducive to TC formation than the average conditions for these months, so that the TC activity can be above normal relative to the mean number for these months. However, even if this is true, the concept here is that the total number *for the year* would *still* likely be below normal. A similar explanation can be given for the above-normal category. In other words, it would be difficult to predict the activity for the remainder of the year *relative to the mean of the remaining months*.

The second issue is how the sample should be divided in categorization II to obtain the results. The current division is based on half a standard deviation rather than terciles, which may sometimes give more cases in the "normal" category. However, using the WNP data as a test, the thresholds determined from the method of terciles are either the same as or deviate by no more than one from those from the current method. Further, because the interest here is on the more extreme situations, the current method actually gives a stronger signal. This can also be seen by comparing the results from the two categorizations, with categorization II giving a much better result for the more extreme situations.

The next step in this investigation is to understand the reasons for those years in which this simple method fails. Such an investigation will help in further enhancing the usefulness of this method.

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